POTROŠNJA TOPLOTNE ENERGIJE GREJANOG STANA PRI NEGREJANJU JEDNOG ILI VIŠE SUSEDNIH STANOVA STAMBENE ZGRADE U KRAGUJEVCU

HEATING CONSUMPTION OF A HEATED APARTMENT DURING UNHEATING OF ONE OR MORE NEIGHBORING APARTMENTS OF A RESIDENTIAL BUILDING IN KRAGUJEVAC

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Zakonom o efikasnom korišćenju energije (Sl.gl. 25/13), predviđeno je da od početka grejne sezone 2014/15. svi sistemi centralnog grejanja u Srbiji pređu na tarifni sistem naplate po utrošku. Upotrebom mernih i regulacionih uređaja potrošači su motivisani da smanje temperaturu vazduha u svojim stanovima. Najveću motivaciju imaju potrošači koji žive u stanovima koji imaju najmanje spoljašnjih (slobodnih) površina. Negativna strana toga je da potrošači koji žive u susednim stanovima imaju veću potrošnju energije za grejanje. Cilj ovog rada je da ukaže na to kako se menja potrošnja energije grajanog stana, tokom grejne sezone i 15 najhladnijih dana u grejnoj sezoni, pri isključivanju grejnih tela u jednom ili više susednih stanova jedne stambene zgrade u Kragujevcu. Za pomenutu analizu odabran je stan koji ima najmanji broj spoljašnjih površina (stan 8). Analiza je uključivala 4 slučaja negrejanja stanova (negrejanje jednog, dva, tri i četiri stana susedna stanu 8). Dobijeni rezultati ukazuju da potrošnja toplotne energije drastično raste sa brojem negrejanih stanova. Procentualno povećanje potrošnje energije, tokom grejne sezone, u okviru stana 8 prema broju negrejanih stanova iznosi, respektivno: 8,77%, 23,59%, 40,31% i 52,33%. Takođe, analizirana je potrošnja toplotne energije stana 8 tokom 15 najhladnijih dana u sezoni. Vrednosti procentualnog povećanja potrošnje toplotne energije za ovaj stan i scenario, prema broju negrejanih stanova iznose, respektivno: 5,47%, 18,81%, 34,30% i 43,09%.

Ključne reči: *potrošnja toplotne energije; simulacija; stambena zgrada;*

Abstract in English. The Law on Efficient Use of Energy (Official Gazette 25/13) provides that from the beginning of the heating season of 2014/2015 all central heating systems in Serbia should switch to the tariff system based on consumption. By using measuring and regulating devices the consumers are motivated to reduce the air temperature in their apartments. The highest motivation have consumers who live in apartments that have minimum outdoor (free) surfaces. The downside of this is that consumers who live in neighboring apartments have a higher heating consumption. The aim of this paper is to indicate how heating consumption of heated apartment changes during the heating season and the 15 coldest days in the heating season, when the heaters in one or more neighboring apartments of a residential building in Kragujevac are turned off. For the mentioned analysis the apartment that has the lowest number of outdoor surfaces (apartment 8) is selected. The analysis includes 4 cases of unheating of apartments (unheating of one, two, three and four apartments adjacent to apartment 8). The results indicate that heating consumption dramatically increases with the number of unheating apartments. Percentage increase of heating consumption during the heating season for the apartment 8 in relation to the number of unheating apartments is, respectively: 8.77%, 23.59%, 40.31% and 52.33%. Also, the heating consumption of the apartment

8 for 15 coldest days of the season was analyzed. The values of the percentage increase of the heating consumption for this apartment and a scenario, in relation to the number of unheating apartments amount, respectively: 5.47%, 18.81%, 34.30% and 43.09%.

Key words: *heating consumption; simulation; residential building;*

I. Introduction

By ratifying the Treaty establishing the Energy Community, the Republic of Serbia took over the obligations of Directive 2009/28 / EC which obliges the Member States of the European Union that by 2020, among other things, reduce greenhouse gas emissions by 20%. The most common measures taken in order to increase energy efficiency and thereby reduce emissions of greenhouse gases are: insulation of a building, replacement of dilapidated windows and doors and installation of measuring and regulating devices (heat meters and thermostatic valves). The Law on Efficient Use of Energy (Official Gazette 25/13) provides that from the beginning of the heating season of 2014/2015 all central heating systems in Serbia should switch to the tariff system based on consumption. It did not happen and the tariff system based on fixed tariff per heated area is still the dominant system of charging. Specifically, in the city of Kragujevac district heating defined per consumption currently pay about 20% of connected consumers in the residential sector. The current tariff systems show that consumers have the highest interest in energy savings if they use gas or electricity for heating. Also, this shows the results of specific heating consumption for these heating systems [1]. By using measuring and regulating devices the consumers are motivated to reduce the air temperature in their apartments. The highest motivation have consumers who live in apartments that have minimum outdoor (free) surfaces. The downside of this is that consumers who live in neighboring apartments have a higher heating consumption. The aim of this paper is to indicate how heating consumption of heated apartment changes during the heating season and the 15 coldest days in the heating season, when the heaters in one or more neighboring apartments of a residential building in Kragujevac are turned off. This paper is a part of investigation that is related to the distribution of heating consumption in one or more apartments during the reduction of air temperature in one or more neighboring apartments of an apartment building.

II. Model

II.1. EnergyPlus software

To simulate thermal behavior of the analysed building and have accurate calculation results, software EnergyPlus (version 7.1.0) was used. This program is very useful tool for modeling of energy and environmental behavior of buildings [2, 3]. EnergyPlus takes into account all factors that influence thermal loads in the building, such as electricity devices, lighting, people in the building, solar radiation, wind, infiltration, and shading of open rooms. In this direction, the complex schedules of heating and cooling can be defined together with schedules for use of lighting, internal energy devices and occupancy in the building.

II.2. Climate

The city of Kragujevac lays on Balkan Peninsula in state of Serbia, south of its capital city of Belgrade. Its average height above sea-level is 185 m. Its latitude is 44.02°N, and longitude 20.92°E. The city has a moderate continental climate with distinct seasons (winter, spring, summer and autumn). The summers are worm and humid, with temperatures as high as 34 °C. The winters are cool, and snowy, with temperatures as low as −19 °C. In relation to this, Table 1 gives the average low and high temperatures, mean precipitation and mean number of precipitation days for each month during entire year [4].

Table 1 *Monthly averages forKragujevac, Serbia [4]*

Months	*Average low temperature* (°C)	*Average high temperature* (°C)	*Average precipitation* (cm)	*Mean number of precipitation days* (days)
January	−3.8	3.8	4.11	11.6
February	−1.7	6.7	3.87	10.4
March	1.4	11.8	4.44	10.6
April	5.5	17.3	4.94	12.2
May	10.1	22.0	7.38	13.1

Months	*Average low temperature* (°C)	*Average high temperature* (°C)	*Average precipitation* (cm)	*Mean number of precipitation days* (days)
June	13.0	25.0	8.47	12.9
July	14.2	25.0	6.8	9.3
August	13.7	27.2	5.33	9.3
September	10.7	23.9	4.48	8.1
October	6.3	18.2	3.82	8.6
November	2.4	11.5	4.82	10.3
December	−1.6	5.6	4.76	12.3

II.3. Description of the residential building

The total area of the analyzed residential building is 1504 m^2 and useful heating area 1247.68 m^2. The building has a total of 24 apartments distributed on 4 levels (Fig. 1). Distribution of apartments per levels is given in Fig. 2.

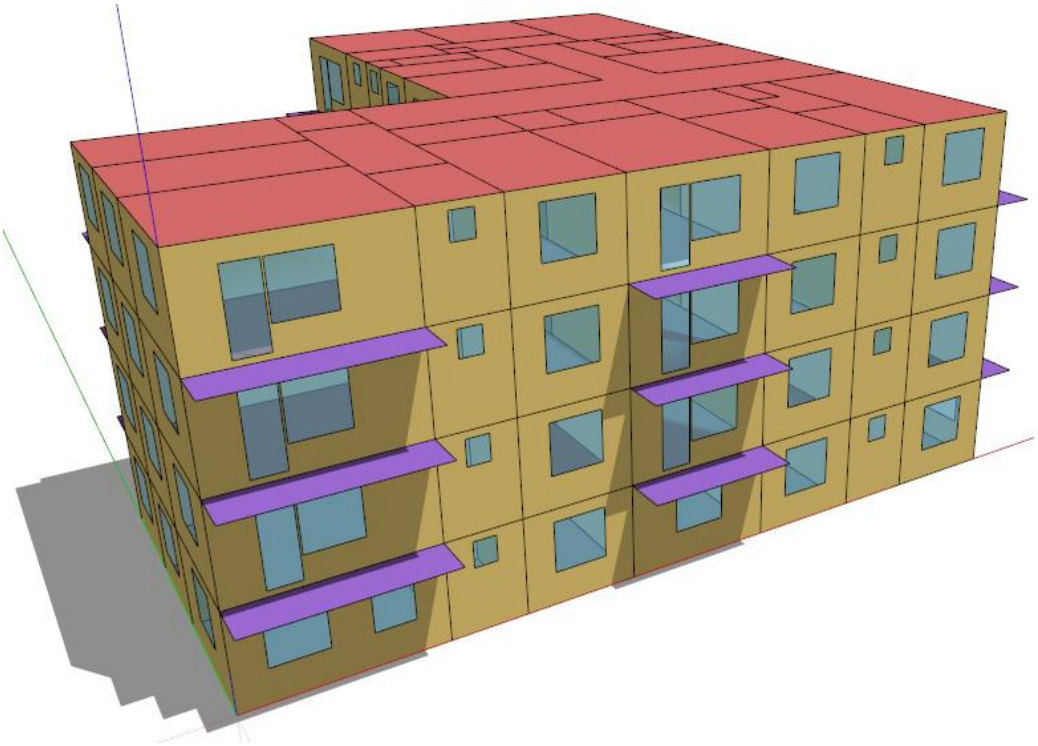

Fig. 1 *Isometric view of the analyzed residential building*

The most apartments consists of: living room, bedroom, kitchen and bathroom. It is assumed that the building is not surrounded with any object. Use of lighting, electric equipment and occupancy in the building is defined by the schedules. Total number of people that accommodates each appartment is: 4 (appartments: 1, 6, 7, 12, 13, 18, 19 and 24), 3 (appartments: 2, 3, 8, 9, 14, 15, 20 and 21) and 2 (appartments: 4, 5, 10, 11, 16, 17, 22 and 23).

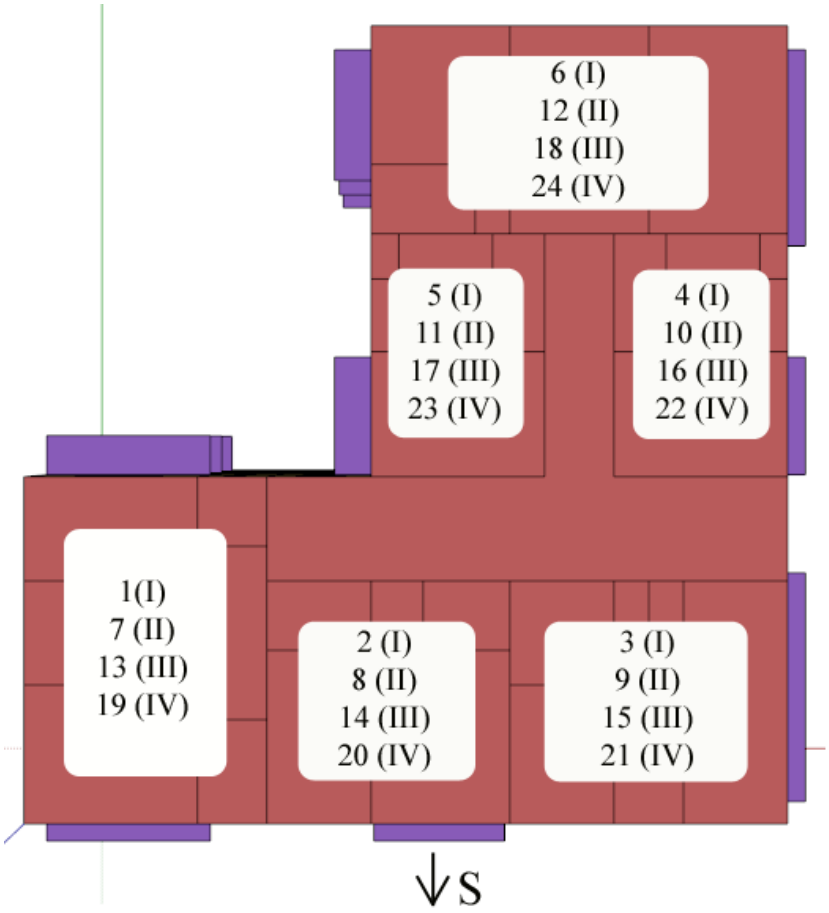

Fig. 2 *Distribution of apartments per levels of the analyzed residential building*

The physical characteristics of the building (the values of the heat transfer coefficient of walls, window, roof, etc.) are given in Table 2.

Table 2 *The characteristics of the constructions used in the building*

Construction	*Layer*	*Heat transfer coefficient* (W/m^2K)
Window and balcony door	Glass (3 mm) Air (13 mm) Glass (3 mm)	2,720
Exterior door	Wood (3,5 cm)	4
Exterior wall	Brick (12 cm) Expanded polystyrene foam (15 cm) Air (2 cm) Clay block (25 cm) Lime mortar (2,5 cm)	0,216
Interior wall	Lime mortar (2,5 cm) Brick (12 cm) Lime mortar (2,5 cm)	2,174
Roof	Gravel (5 cm) Waterproofing (0,2 cm) Vapor barrier (0,2 cm) Cotton (5 cm) Vapor barrier (0,2 cm) Lightweight concrete 1 (5 cm) Lightweight concrete 2 (4 cm) Lightweight concrete 3 (16 cm) Lime mortar (2,5 cm)	0,512

Floor with tiles	Stone (25 cm) Gravel (5 cm) Lightweight concrete 2 (4 cm) Waterproofing (0,8 cm) Lightweight concrete 2 (4 cm) Ceramic tile (1,5 cm)	1,677
Floor with hardwood	Stone (25 cm) Gravel (5 cm) Lightweight concrete 2 (4 cm) Waterproofing (0,8 cm) Lightweight concrete 2 (4 cm) Hardwood (2 cm)	1,464
Interior ceiling (with tiles)	Lime mortar (2,5 cm) Lightweight concrete 3 (20 cm) Ceramic tile (1,5 cm)	2,058
Interior ceiling (with hardwood)	Lime mortar (2,5 cm) Lightweight concrete 3 (20 cm) Hardwood (2 cm)	1,767

The building is heated by hot water from the heating system that consists of a boiler on natural gas, convective baseboard heaters and variable flow pump. The water convective baseboard heaters are put in each of the heated rooms. The heating system operates each day from 7:00 am to 10:00 pm during the heating season from 15th of October to 15th of April. Air temperatures in the heated rooms are set to 20 $^{\circ}$C for living room, bedroom and kitchen and 24 $^{\circ}$C for bathroom.

III. Results and discussion

In this paper the energy consumption of heated apartment is analyzed, surrounded with one or more unheated apartments, during the heating season (15.10.-15.04.) and 15 coldest days in the heating season (01.01.-15.01.). The initial data for the entire analysis represents the amount of energy needed for heating apartments for the whole heating season (Fig. 3), in the case when all apartments are heated. From the figure it can be seen that the apartments that are on the top level of the building (apartments 19-24), require the highest amount of energy for heating. These apartments have the highest number of free (outdoor) surfaces or the lowest number of boundary surfaces. The maximum value is for apartment 22 with slightly over 68 kWh/m^2 per heating season. On the other hand, apartment 8 has the lowest consumption of 31.57 kWh/m^2. The reason for this lies in the fact that it is "tucked" or that has the highest number of boundary surfaces. Because of its location within the building and the fact that it has the lowest number of free surfaces (only one), apartment 8 is most suitable for this analysis.

The analysis of energy consumption for the apartment 8 included 4 cases. The first case relates to turning off heaters in one neighboring apartment (apartment 9), the second case in two (apartments 9 and 2), the third case in three (apartments 9, 2 and 14) and fourth in all four apartments with which the apartment 8 is connected (apartments 9, 2, 14 and 7). Percentage increase of heating consumption after turning off heaters in one or more apartments, during the heating season is shown in Fig. 4.

In the first case all heaters in the apartment 9 are turned off. The apartment 8 is connected with apartment 9 on its eastern side. From the figure it can be seen that heating consumption for those apartments that are in direct contact (adjacent to) with the unheated apartment significantly increased: the apartment 15, the increase of energy consumption of 18.75%; the apartment 3, the increase of energy consumption of 17.96% and the apartment 8, the increase of energy consumption of 8.77%. For the other apartments higher increase of consumption of 3% is not recorded (apartments 2, 14 and 21).

In the second case all heaters in the apartments 9 and 2 are turned off. The apartment 8 is located above the apartment 2. The increase of heating consumption is recorded for the following apartments: the apartment 8, the increase of energy consumption of 23.59%; the apartment 3, the increase of energy consumption of 23.49% and the apartment 15, the increase of energy consumption of 19.67%. Among other apartments significantly increased consumption is recorded in the apartments 1 and 14, with an increase of slightly over 5%.

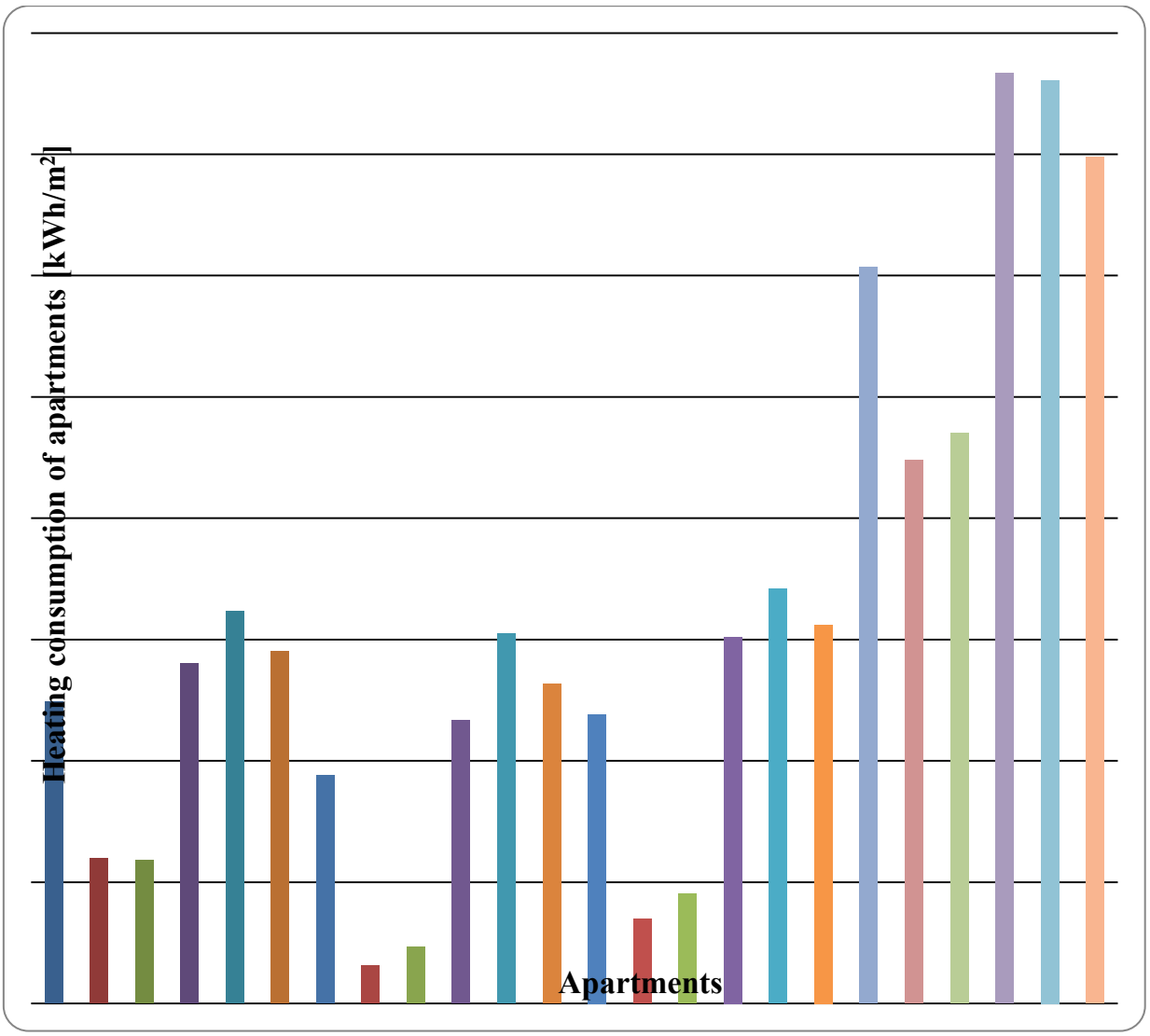

Fig. 3 *Heating consumption of apartments (kWh/m^2)(for the heating season)*

The third case relates to turning off all heaters in the apartments 9, 2 and 14. The apartment 8 is located below the apartment 14. The apartments that are marked as apartments with increased energy consumption are: the apartment 8, the increase of energy consumption of 40.31%; the apartment 15, the increase of energy consumption of 26.62%; the apartment 3, the increase of energy consumption of 24.51% and the apartment 20, the increase of energy consumption of 12.71%. For the other apartments recorded increase of heating consumption is to a maximum of 6.5% (the apartment 13).

The fourth case relates to the turning off all heaters in all apartments that are adjacent to the apartment 8. These are apartments 9, 2, 14 and 7. The apartment 8 is connected with the apartment 7 on its western side. Drastically increase of heating consumption is recorded for the following apartments: the apartment 8, the increase of energy consumption of 52.33%; the apartment 15, the increase of energy consumption of 27.31%; the apartment 13, the increase of energy consumption of 25.66%; the apartment 3, the increase of energy consumption of 25.08%; the apartment 1, the increase of energy consumption of 24.52% and the apartment 20, the increase of energy consumption of 13.78%. For the other apartments the increase of energy consumption is in the range of 0.5% - 6%.

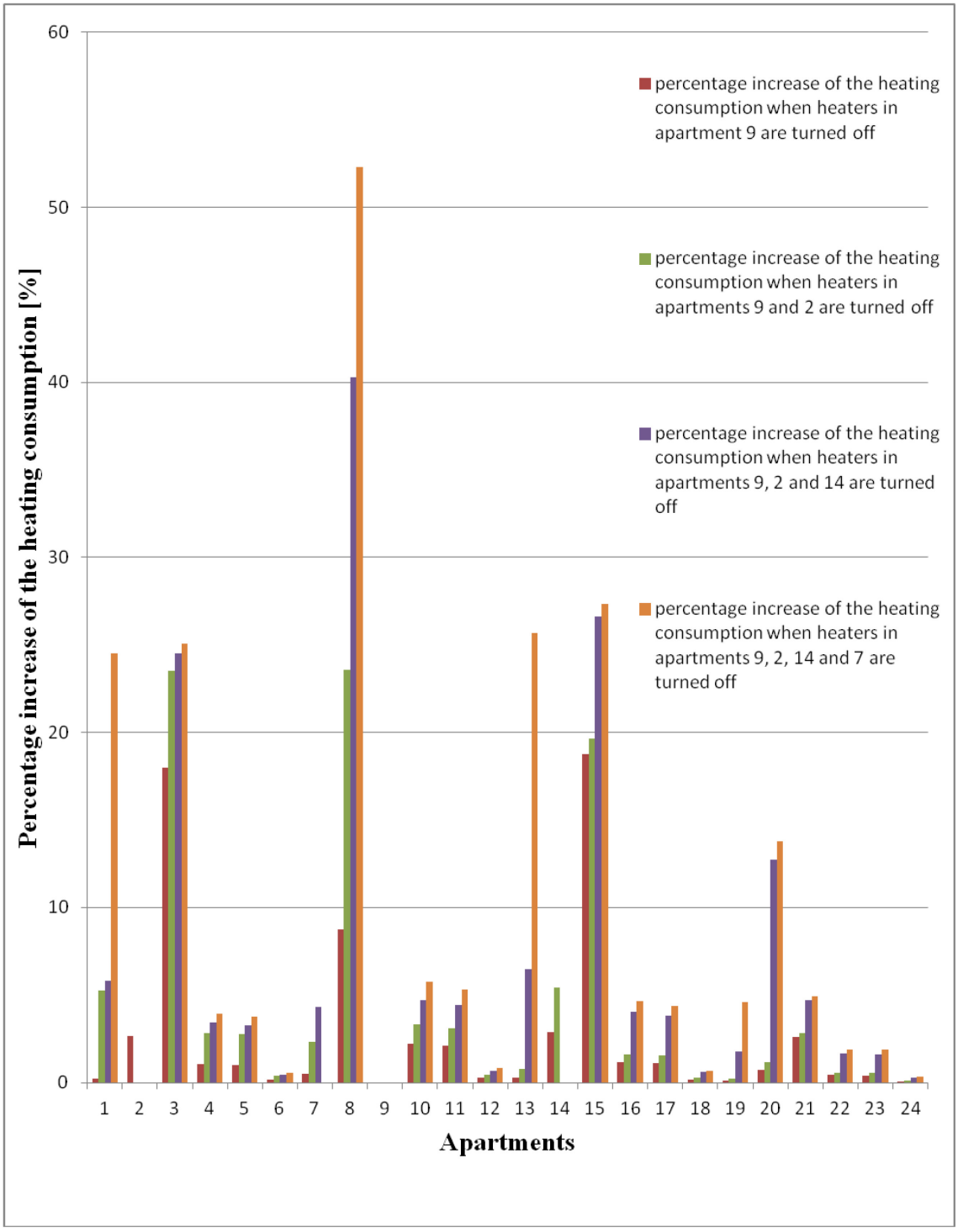

Fig. 4 *Percentage increase of the heating consumption in apartments for the heating season when heaters in the apartments 9,2,14 and 7 are turned off*

Table 3 shows the mean air temperature in the living room (LR) and the bathroom (BR) within the apartments 2, 7, 8, 9 and 14 before and after turning off all heaters in one or more apartments during the heating season. In the case when in all apartments all heaters were working temperatures ranged around the set values (20 °C for the living room and 24 °C for bathroom). An exception are apartments which are located on the southern and eastern side of the building (apartments, 8, 9 and 14), for which slightly higher values of temperature in living rooms can be overwritten to solar gains. After turning off the heaters in certain aparments temperatures in these apartments were lower. Also, within the apartment 8 air temperature was lower. The values of temperature drops were in the range of 2.4 °C (the apartment 14) to 4.1 °C (the apartment 7) for LR or of 5.4 °C (the apartment 14) to 5.8 °C (the apartment 7) for BR. Of all the mentioned apartments the lowest temperature drop is recorded in the apartment 8 (0.1-0.6 °C (LR) and 0.4-1 °C (BR)) as a result of its characteristic position within the building.

Table 3 *Preview of air temperatures in the living room (LR) and the bathroom (BR) within the apartments 2, 7, 8, 9 and 14 before and after the turning off all heaters in one or more apartments during the heating season*

	t (°C) - without unheated apartments		*t (°C) - with unheated apartment 9*		*t (°C) - with unheated apartments 9 and 2*		*t (°C) - with unheated apartments 9, 2 and 14*		*t (°C) - with unheated apartments 9, 2, 14 and 7*	
Room	LR	BR	LR	BR	LR	BR	LR	BR	LR	BR
Apa. 2	20,2	22,5	20,2	22,4	17,8	16,9	17,7	16,9	17,7	16,6
Apa. 7	20,0	23,7	20,0	23,7	20,0	23,6	20,0	23,6	15,9	17,9
Apa. 8	21,2	23,1	21,1	23,1	20,9	22,7	20,7	22,4	20,6	22,1
Apa. 9	21,4	23,7	18,5	18,1	18,5	18,1	18,4	18,0	18,3	17,9
Apa. 14	21,4	23,2	21,4	23,2	21,4	23,1	19,1	17,8	18,9	17,5

The second scenario relates to the analysis of the heating consumption for the apartment 8 for 15 coldest days in the heating season (01.01.-15.01.). By this the situation when tenants in one or more neighboring apartments turn off heaters because of going on the winter holidays is simulated. Due to the similarity of results of heating consumption and mean temperatures in the LR and BR for this scenario in relation to the previous scenario for the heating season the same are not diagrammatically presented. It is important to note that, according to this scenario, the percentage increase of energy consumption within the apartment 8 per number of unheated apartments is respectively: 5.47%, 18.81%, 34.30% and 43.09%.

IV. Conclusions

In this paper the heating consumption of heated apartment during the whole heating season and 15 coldest days of the season, during the unheating of one or more neighboring apartments within an residential building in Kragujevac is analyzed. Simulation of the energy behavior of the residential building, with useful heating area of 1247.68 m^2, was performed by using software EnergyPlus. For the mentioned analysis the apartment that has the lowest number of free (outdoor) surfaces (the apartment 8) is selected. The analysis included 4 cases of unheating of apartments (unheating of one, two, three and four apartments adjacent to the apartment 8). The obtained results indicate that the heating consumption dramatically increases with the number of unheated apartments. Percentage increase of energy consumption during the heating season for the apartment 8 per number of unheated apartments is, respectively: 8.77%, 23.59%, 40.31% and 52.33%. It is easy to conclude that the highest energy consumption is for the case of unheating of all neighboring apartments. Also, for the case of unheating of all neighboring apartments the mean air temperature in the living room and bathroom of the apartment 8 during the heating season was approximately the same as the set one as a consequence of its characteristic position within the residential building. Also, the heating consumption of the apartment 8 for 15 coldest days of the season was analyzed. The values of the percentage increase of the heating consumption for this apartment and the scenario, per number of unheated apartments are, respectively: 5.47%, 18.81%, 34.30% and 43.09%.

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